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Original Study

Differences in Nutrient Intake and Biochemical Nutrient Status Between Sarcopenic and Nonsarcopenic Older Adults—Results From the Maastricht Sarcopenia Study

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A B S T R A C T

Background: There is growing evidence of a relationship between nutrients and muscle mass, strength, and physical performance. Although nutrition is seen as an important pillar of treating sarcopenia, data on the nutritional intake of sarcopenic older adults are limited.
Objective: To investigate potential nutritional gaps in the sarcopenic population, the present study compared nutrient intake and biochemical nutrient status between sarcopenic and nonsarcopenic older adults.
Design: The Maastricht Sarcopenia Study included 227 community-dwelling older adults (≥65 years) from Maastricht, 53 of whom were sarcopenic based on the European Working Group on Sarcopenia in Older People algorithm. Habitual dietary intake was assessed with a food frequency questionnaire and data on dietary supplement use were collected. In addition, serum 25-hydroxyvitamin D, magnesium and α-tocopherol/cholesterol, plasma homocysteine and red blood cell n-3, and n-6 fatty acids profiles were assessed. Nutrient intake and biochemical nutrient status of the sarcopenic groups were compared with those of the nonsarcopenic groups. The robustness of these results was tested with a multiple regression analysis, taking into account between-group differences in characteristics.
Results: Sarcopenic older adults had a 10%–18% lower intake of 5 nutrients (n-3 fatty acids, vitamin B_6, folic acid, vitamin E, magnesium) compared with nonsarcopenic older adults ($P < .05$). When taking into account dietary supplement intake, a 19% difference remained for n-3 fatty acids intake ($P = .005$). For the 2 biochemical status markers, linoleic acid and homocysteine, a 7% and 27% difference was observed, respectively ($P < .05$). The higher homocysteine level confirmed the observed lower vitamin B intake in the sarcopenic group. Observed differences in eicosapentaenoic acid and 25-hydroxyvitamin D between the groups were related to differences in age and living situation.
Conclusions: Sarcopenic older adults differed in certain nutritional intakes and biochemical nutrient status compared with nonsarcopenic older adults. Dietary supplement intake reduced the gap for some of these nutrients. Targeted nutritional intervention may therefore improve the nutritional intake and biochemical status of sarcopenic older adults.

The average age of the world's population is rapidly increasing. The United Nations estimates that from 2015 to 2050, the proportion of adults aged 65 years and older will increase from 8% to 16%.[1] With the increased life expectancy, the number of older adults who are care-dependent will also rise, with an expected 4-fold increase by 2050.[2] This emphasizes the importance of promoting healthy aging, adding quality to the years lived, and prolonging independence and aging in place.

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One of the suggested causes of the loss of independence is sarcopenia.[3] The geriatric syndrome sarcopenia is defined by the European Working Group on Sarcopenia in Older People, as the loss of muscle mass, strength, and physical performance.[4] Based on this definition, up to 29% of community-dwelling older adults are sarcopenic.[5] Multiple risk factors are identified for sarcopenia, including among others, physical inactivity, chronic diseases, malnutrition, and low protein intake.[3]

Nutrition, and nutrition in combination with exercise, are seen as important pillars for the treatment and prevention of sarcopenia, and an optimal quantity and quality of dietary protein and adequate 25-hydroxyvitamin D levels are recommended by international societies.[6,7] In addition to protein and vitamin D, the B vitamins, antioxidants and omega 3 fatty acids have been found to be related to sarcopenia determinants (ie, muscle mass, strength, and physical performance).[8,9]

Only a few studies have assessed the dietary intake of sarcopenic older adults. The Korea National Health and Nutrition Examination Survey (KNHANES) cohort observed a lower energy, protein, carbohydrate, and calcium intake among sarcopenic older adults.[10,11] Adhering to a Mediterranean diet was found to be inversely associated with sarcopenia in Iranian older adults.[12]

The aim of the present study was to provide a comprehensive assessment of the nutrient intake and biochemical nutrient status of Dutch sarcopenic older adults, and to investigate if there are nutritional differences compared with nonsarcopenic older adults. Data from the Maastricht Sarcopenia Study (MaSS)[13] were used.

Methods

MaSS (clinicaltrials.gov #NCT01820988) is a cross-sectional study in which the characteristics, prevalence, and consequences of sarcopenia were assessed in community settings. For details on the study design and sarcopenia assessment see the original publication by Mijnarends et al.[13] In short, participants were recruited from May 2013 to March 2014 in Maastricht, The Netherlands. Older adults (aged ≥65 years) were eligible if they were living at home with or without professional home care, or living in an assisted or residential living facility and had an understanding of the Dutch language. In total 247 home visits were performed. Assessments took place during a 1- to 2-hour home visit, following standardized protocols. Older adults were excluded if they had a cognitive function (Mini-Mental State Examination (MMSE))[14] score <24, or if the assessments could not be performed (ie, prosthesis, pacemaker, wheelchair bound or bedridden, severe active rheumatoid arthritis, acute angina pectoris, poststroke status with evident lingering symptoms, diseases of the nervous system, or dementia). Informed consent was obtained from all participants, and ethics approval was obtained from the Medical Ethics Committee of the Academic Hospital Maastricht and Maastricht University.

Participant Characteristics

During the home visit, the following participant characteristics were obtained via a questionnaire: sex, age, living situation, cognitive function (MMSE), ethnicity, smoking status, alcohol use, and comorbidities (Charlson Comorbidity Index[15]). Body height and weight were assessed with a stadiometer (SECA 213, Seca, Hamburg, Germany) and scale (SECA 877), respectively. Body mass index (BMI) was calculated as weight in kg divided by height in m^2. In addition, information was collected on physical activity with the Minnesota Leisure Time Physical Activity Questionnaire.[16,17]

Assessment of Sarcopenia

Sarcopenia was assessed following the European Working Group on Sarcopenia in Older People algorithm,[4] including low muscle mass and poor grip strength and/or slow gait speed. In short, muscle mass was assessed after an overnight fast, by using bio-electrical impedance (Aker BIA 50 kHz; Akern Srl, Florence, Italy).[18] Skeletal muscle mass (SMM) was calculated based on the Janssen equation.[19] Skeletal muscle index (SMI) was calculated as SMM divided by height in m^2. Muscle mass was considered low if SMI ≤10.75 kg/m^2 in men and ≤6.75 kg/m^2 in women,[20] thereby including both severe and moderate sarcopenia. Muscle strength was assessed with the Jamar handheld dynamometer (Sammons Preston, Inc, Warrenville, IL). Three attempts were performed per hand, with alternating the left and right hand. The best attempt, the maximum grip strength, was used as the outcome measure. Muscle strength was defined as poor if <20 kg in women and <30 kg in men.[21] Gait speed was measured during a 4-meter walk test and considered slow if ≤0.8 m/s.[4,21,22]

Energy and Nutrient Intake and Malnutrition Assessment

Habitual dietary intake was assessed with the food frequency questionnaire (FFQ) FQ29, which contains 67 questions and 104 items. The FQ29 was generated by the validated Dutch FFQ-TOOL™.[23] The Dutch food composition table of 2010[24] was used for calculating the nutrient intake per day. Portion sizes were based on standard weights.[25] The FQ29 assesses dietary intakes of energy, carbohydrates, protein, fat, total n-3 fatty acids [sum of α-linolenic acid (ALA, 18:3*n*-3), 18:4*n*-3, 20:3*n*-3, 20:4*n*-3, eicosapentaenoic acid (EPA, 20:5*n*-3), 22:3*n*-3, docosapentaenoic acid (DPA, 22:5*n*-3), and docosahexaenoic acid (DHA, 22:6*n*-3)], ALA, EPA, DHA, alcohol, calcium, magnesium, zinc, selenium, vitamins B_6, B_{12}, C, D, E, and folic acid equivalents. These nutrients were selected based on previous studies indicating associations between these nutrients and the determinants of sarcopenia.[26–32] In order to test the feasibility of the full set of MaSS assessments, a pilot study was performed in 8 older adults [assisted living (n = 4), residential living facility (n = 4)].[33,34] Based on this pilot study, it was decided to add an example page to the FFQ to increase the comprehensibility. Study participants were asked to fill in the paper version of the FFQ before the study visit. During the visit, the FFQ was checked for completeness, and additional information was added by the researchers if needed. Data were entered in the online FFQ-TOOL™ by 2 researchers, and a full data entry check was performed by a nutritionist. Dietary supplement intake was recorded separately, including details on supplement name, dose, and composition. From here on the term "dietary intake" will comprise the results from the FFQ, whereas "nutrient intake" includes the total intake: the sum of the dietary and supplement intake. The Mini Nutritional Assessment Short-Form (MNA-SF®)[35,36] was used to determine the presence of malnutrition.

Biochemical Markers of Nutrient Status

Blood samples were collected during the home visit, after an overnight fast. The following biochemical markers were assessed: 25-hydroxyvitamin D, magnesium, red blood cell (RBC) n-3, and n-6 fatty acid profile. The RBC fatty acid profiles were used to determine the percentage of total n-3, total n-6, EPA, DPA, DHA, linoleic acid (LA, 18:2*n*-6) and arachidonic acid (AA, 20:4*n*-6). The sum score of n-3 fatty acids was defined as the sum of ALA, 18:4*n*-3, 20:3*n*-3, EPA, 22:3*n*-3, DPA, and DHA. The sum score of n-6 fatty acids was defined as the sum of LA, 18:3*n*-6, 20:2*n*-6, 20:3*n*-6, AA, 22:4*n*-6, 22:5*n*-6, and 24:2*n*-6. As a marker for antioxidant status, α-tocopherol levels were assessed and corrected for cholesterol. Plasma homocysteine was measured as an indirect status marker for B vitamins B_6, B_{12} and folate. Blood was collected in ethylenediaminetetraacetic acid-containing tubes for analysis of the lipid profile, in serum tubes for analysis of 25-hydroxyvitamin D, magnesium, α-tocopherol and cholesterol, and in Sarstedt tubes for the analysis of homocysteine. Blood samples were centrifuged directly following the home visits. RBCs were washed

(0.9% NaCl). Aliquots were stored at −80°C until analysis. Serum 25-hydroxyvitamin D concentration was determined with the chemiluminescence IDS-iSYS 25-Hydroxy Vitamin D^{s} assay (Immunodiagnostic Systems Ltd, Boldon, England). Serum magnesium was determined photometrically with Magnesium Gen.2 (COBAS, Roche Diagnostics GmbH, Mannheim, Germany). Lipids were extracted from RBCs and were assessed qualitatively as percentage of the total lipid fraction, with gas chromatography (Shimadzu Benelux, 's-Hertogenbosch, The Netherlands). Serum α-tocopherol was assessed with ultra-fast liquid chromatography (Shimadzu Benelux). Cholesterol was assessed with the colorimetric method Cholesterol Gen.2 (COBAS, Roche Diagnostics GmbH). Plasma homocysteine, was analysed with a Quattro Premier tandem mass spectrometer (Waters Chromatography B.V., Etten-Leur, The Netherlands).

Data Analyses

For data interpretation, energy and nutrient intakes were compared with the nutritional reference values and data from existing cohorts. For a complete overview of the nutritional reference values used see Appendix Table A1. The nutritional reference values were selected based on the most recent recommendations in the following order: (1) the Dutch Health Council, (2) the Nordic Nutrition Recommendations; and (3) European Food Safety Authority, as advised by The Netherlands Nutrition Center Foundation.[37] The acceptable macronutrient distribution range (AMDR) and the estimated average requirement (EAR) were used. If an EAR was not stated, the adequate intake was used. A MNA-SF® score of 0–7 was considered to represent malnutrition, 8–11 risk of malnutrition, and 12–14 no malnutrition.[35]

Serum magnesium levels were considered deficient if below 0.75 mmol/L.[38] Serum α-tocopherol levels were considered low if the α-tocopherol-cholesterol ratio was below 2.25 μmol/mmol.[39] Serum 25-hydroxyvitamin D levels below 50 nmol/L were considered deficient.[40] Plasma homocysteine levels above 15 μmol/L were considered above the normal physiological range[38,41] and indicated low levels of vitamins B_6, B_{12} and/or folate.

Comparisons between groups were made using the 2 independent samples *t*-test. The Shapiro-Wilks test with alpha 0.01 was used to determine if the distribution of continuous variables deviated from the normal distribution in which case the nonparametric Wilcoxon rank sum test was used. For categorical variables, comparisons between groups were made using the χ^2 test. Multiple regression analyses were used, taking possible covariates into account, thereby determining whether the nutrient intake and biochemical nutrient status differences between the groups were indeed related to sarcopenia and not to other participant characteristics. The following covariates were included for the evaluation of dietary and nutrient intake: age, sex, MNA-SF score and malnutrition category, living-situation, ethnicity, smoking status, alcohol drinking status and amount of alcohol consumed, MMSE, comorbidities, weight, height, BMI, physical activity, and energy intake. For the biochemical nutrient status, in addition, dietary supplement use was included as a covariate. The multiple regression analysis were performed by including all covariates in 1 model, followed by an analysis in which the covariates were tested one by one in separate models. Based on the results, subsequent subgroup analyses (for age categories and living situations) were performed by 1-way analysis of variance and Tukey all-pairs comparison. Results were considered statistically significant when the *P* value was <.05. Analyses were performed in SAS Enterprise Guide v 4.3 (SAS Institute Inc., Cary, NC).

Results

In total, 227 participants had complete data sets and were included in the analysis. For the flow diagram on participant selection see Figure 1. Participants without FFQ data (n = 1) or when no blood sample was available (n = 1) were excluded from the intake and biochemical status analysis, respectively. Population characteristics and differences between the sarcopenic and nonsarcopenic groups are shown in Table 1. Fifty-three participants (23%) were identified as being sarcopenic. The median age of the MaSS participants was 74 years, with the sarcopenic group being significantly older than the nonsarcopenic participants (81 vs 72 years of age, respectively, $P < .001$). Of the MaSS population, 9% was at risk of malnutrition and 1% was malnourished, with no significant difference in the MNA-SF categories between the sarcopenic and nonsarcopenic ($P = .194$). Although the MNA-SF® score was significantly different between the 2 groups ($P = .039$), both groups had a median score at the upper limit of 14. The sarcopenic older adults lived more frequently in a care providing setting ($P < .01$), had a higher number of comorbidities ($P < .001$), and a lower MMSE score ($P = .003$). Median MMSE score was however near the maximum of 30 in both the sarcopenic and nonsarcopenic group. Body height ($P = .007$), weight ($P = .002$), and BMI ($P = .048$), were lower in the sarcopenic older adults compared with the nonsarcopenic older adults. The difference between the groups in sarcopenia status was confirmed by significantly lower SMM ($P = .003$), SMI ($P = .020$), handgrip strength ($P < .001$), gait speed ($P < .001$), and physical activity ($P < .001$) in the sarcopenic group.

Dietary and Nutrient Intake

The dietary and nutrient intakes of the total MaSS population and the sarcopenic and nonsarcopenic groups are shown in Table 2. Sarcopenic and nonsarcopenic group comparisons were made for both dietary intake and nutrient intake. Overall, dietary supplement use seemed less in the sarcopenic older adults compared with the nonsarcopenic older adults (34% vs 42%, respectively), although this difference was not statistically significant. When considering dietary intake only, significant lower intakes were found between sarcopenic and nonsarcopenic groups for protein (g/d), n-3 fatty acids, ALA, vitamin B_6, folic acid equivalents, vitamin E, magnesium, and selenium. Vitamin D intake was lower in the sarcopenic group, although not significant ($P = .053$). Differences in n-3 fatty acids, vitamin B_6, folic acid equivalents, vitamin E, and magnesium were robust, taking the covariates into account, with a 10%–18% lower intake in the sarcopenic group compared with the nonsarcopenic group. Correcting for the covariates, however, decreased the significance of the differences in protein (g/d), ALA, and selenium intake to the level that the difference was no longer statistically significant. When taking dietary supplement intake into account, similar nutrients were identified to differ between the groups (protein (g/d), n-3 fatty acids, ALA, folic acid, magnesium). Differences in vitamin B_6, vitamin E, and selenium were, however, no longer significant. Differences in n-3 fatty acids remained robust with a 10% and 19% (n-3 fatty acids expressed as En% and g/d, respectively) difference between the 2 groups, whereas the differences in protein (g/d), ALA, folic acid equivalents, and magnesium intake were no longer significant, based on the analysis taking the covariates into account. Examples of possible confounding factors were energy intake and weight (Table 2).

Compared with the nutritional reference values (Appendix Table A1), most mean nutrient intakes of the total MaSS population were above the reference values. The mean energy intake of men and the carbohydrate intakes of men and women were, however, below the reference values. Although the mean protein intake was within the AMDR of 15–20 En%, 25% of the sarcopenic group and 12% of the nonsarcopenic group were below the EAR of 0.66 g/kg bw/d. Compared with the AMDR derived reference value, 74% and 81% were below 1.2 g/kg bw/d for sarcopenic and nonsarcopenic, respectively. The mean intakes of EPA, DHA, and of selenium were below the adequate intakes. Vitamin D intake was considerably lower than the

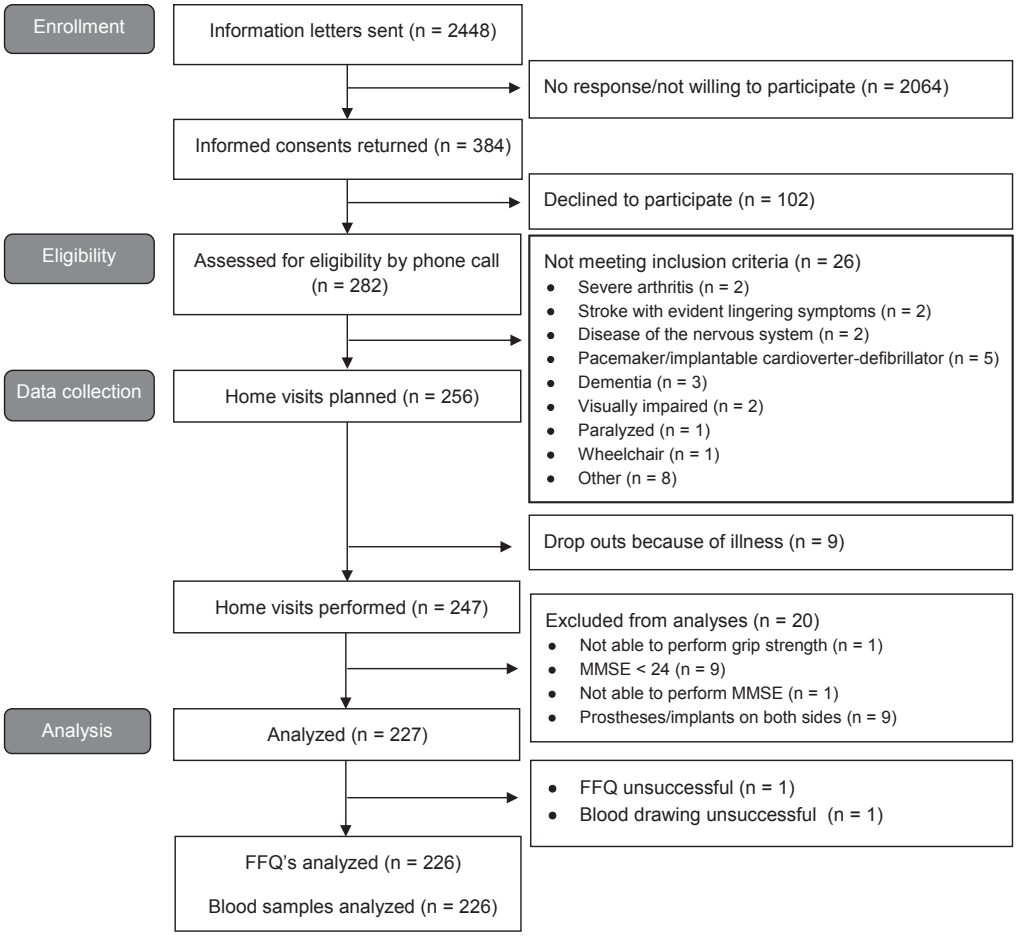

Fig. 1. Flow diagram of the inclusion of MaSS participants, adapted from Mijnarends et al.[13]

EAR, with 100% in the sarcopenic groups and 99% in the nonsarcopenic group below 20 μg/d.

Biochemical Markers of Nutrient Status

Biochemical nutrient levels of the MaSS population and sarcopenic and nonsarcopenic groups are shown in Table 3. The sarcopenic group had significant, 7%–20% lower levels of EPA, LA, and 25-hydroxyvitamin D, compared with the nonsarcopenic group. Homocysteine levels were significantly higher in the sarcopenic group, with a 27% higher level than the nonsarcopenic group. Age was identified as a covariate for both EPA ($P = .048$) and 25-hydroxyvitamin D ($P \leq .001$). Correcting for this covariate decreased the significance of the group differences in EPA and 25-hydroxyvitamin D levels to the level that the difference was no longer statistically significant ($P = .108$, $P = .367$, respectively). In addition, living situation was identified as a covariate for EPA ($P = .002$) and 25-hydroxyvitamin D ($P < .001$). As with age, correcting for living situation decreased the significance of the differences in EPA and 25-hydroxyvitamin D to the levels that the differences were no longer statistically significant ($P = .247$, $P = .426$, respectively). The observed differences in EPA and 25-hydroxyvitamin D between the groups were, therefore, related to differences in age and living situation. To illustrate, a significant difference was observed for EPA status between the age categories ($P = .024$, based on overall test) and living situations ($P < .001$, based on overall test) (Figure 2). The same was observed for 25-hydroxyvitamin D status for both the age categories ($P < .001$) and living situations ($P < .001$) (Figure 3). Lower levels of both EPA and 25-hydroxyvitamin D were present in those aged 86–95 years compared with those aged 65–75 years ($P = .023$, $P < .001$, respectively). Those living in residential care had lower levels of EPA and 25-hydroxyvitamin D compared with those living independently ($P < .001$, $P < .001$, respectively, for overall test).

Although the mean 25-hydroxyvitamin D status of the MaSS participants was above the reference value, 51% of the sarcopenic group and 25% of the nonsarcopenic group had a status below 50 nmol/L. The sarcopenic older adults had a mean homocysteine level slightly above the cut-off value of 15 μmol/L. In the sarcopenic group 33% was above 15 μmol/L compared with 16% in the nonsarcopenic group. No major deficiencies were observed for magnesium and α-tocopherol.

Discussion

Our results indicate that sarcopenic older adults had a lower intake of 5 nutrients (n-3 fatty acids, vitamin B_6, folic acid, vitamin E, and magnesium) compared with nonsarcopenic older adults. When considering dietary supplement intake, 1 nutrient (n-3 fatty acids) was lower in the sarcopenic older adults. The supplement intake, therefore, seems to decrease the intake gap between the sarcopenic and nonsarcopenic older adults. In addition, 2 biochemical markers (LA and homocysteine) differed between the 2 groups, with lower LA and higher homocysteine levels in the sarcopenic older adults. The higher homocysteine level confirmed the observed lower vitamin B intake in the sarcopenic group.

Scientific literature and sarcopenia guidelines indicate that dietary protein is an important pillar of sarcopenia treatment, as older adults have an increased need for dietary protein to stimulate their muscle

Table 1
Characteristics of the MaSS Participants

	Total (n = 227)	Nonsarcopenic (n = 174)	Sarcopenic (n = 53)	*P* Value
Sex, n (%)				
Male	110 (49%)	85 (49%)	25 (47%)	.830*
Female	117 (52%)	89 (51%)	28 (53%)	
Age, years	74 (69–79)	72 (68–76)	81 (77–86)	<.001†
MNA-SF® categories, n (%)				
Nonmalnourished	204 (90%)	157 (90%)	47 (89%)	.194*
At risk	20 (9%)	16 (9%)	4 (8%)	
Malnourished	3 (1%)	1 (1%)	2 (4%)	
MNA-SF® score	14 (13–14)	14 (13–14)	14 (12–14)	.039†
Living situation, n (%)				
Independent living	157 (69%)	138 (79%)	19 (36%)	<.001*
Home care/assisted living	41 (18%)	24 (14%)	17 (32%)	
Residential home	29 (13%)	12 (7%)	17 (32%)	
Ethnicity, n (%)				
Caucasian	221 (97%)	171 (98%)	50 (94%)	.118*
Asian	6 (3%)	3 (2%)	3 (6%)	
Smoking status, n (%)				
No	79 (35%)	60 (35%)	19 (36%)	.983*
Formerly	126 (56%)	97 (56%)	29 (55%)	
Yes	22 (10%)	17 (10%)	5 (9%)	
Consume alcohol, n (%)				
No	26 (12%)	19 (11%)	7 (13%)	.657*
Yes	200 (89%)	154 (89%)	46 (87%)	
Taking nutritional supplements, n (%)				
No	136 (60%)	101 (58%)	35 (66%)	.299*
Yes	91 (40%)	73 (42%)	18 (34%)	
MMSE score	29 (28–30)	29 (28–30)	28 (28–29)	.003†
Number of comorbidities	2.0 (1.0–3.0)	1.0 (1.0–3.0)	3.0 (1.0–4.0)	<.001†
Body composition				
Weight, kg	76.0 (67.7–83.2)	77.0 (69.1–83.7)	71.5 (59.3–79.5)	.002†
Height, m	1.67 (0.09)	1.68 (0.09)	1.64 (0.09)	.007‡
BMI, kg/m^2	26.6 (24.6–29.4)	26.8 (24.7–29.6)	26.1 (23.5–28.2)	.048†
SMM, kg	23.5 (17.1–28.4)	24.0 (17.7–28.8)	22.7 (15.2–26.3)	.003†
SMI, kg/m^2	8.3 (6.7–9.5)	8.4 (6.9–9.5)	7.9 (6.1–9.4)	.020†
Physical function				
Hand grip strength, kg	26.4 (9.7)	28.7 (9.2)	18.8 (7.1)	<.001‡
Gait speed, m/s	1.01 (0.27)	1.08 (0.24)	0.76 (0.23)	<.001‡
Physical activity, kcal/week	1893 (636–3431)	2230 (1074–3646)	765 (246–2083)	<.001†

SD, standard deviation.
Data are presented as n (%), mean (SD) or median (Q1-Q3).
*χ^2 test.
†Nonparametric Wilcoxon rank sum test.
‡2 independent samples *t*-test.

protein synthesis.[6,7] In the present study, a significant difference in protein intake (in g/d) was found between sarcopenic and nonsarcopenic older adults. The multiple regression analysis indicated that the difference in protein intake is related to the difference in, amongst others, energy intake and MNA-SF® score. A low energy intake can increase the risk of a low protein intake, and adequate daily protein intake is, therefore, important to monitor. The relative measure of protein intake adjusted for bodyweight (in g/kg bw/d) might be less appropriate for detecting differences between sarcopenic and nonsarcopenic older adults, when groups differ in bodyweight and SMI, as was the case in this study.

N-3 fatty acids are mentioned as part of an integrated management of sarcopenia, combined with physical activity, protein, and vitamin D.[42] We observed a significant difference in RBC EPA levels between the sarcopenic and nonsarcopenic groups. The analysis taking into account possible covariates and the subgroup analysis, however, indicate that this difference was related to a difference in age and living situation, rather than primarily because of the presence of sarcopenia. This decrease in RBC EPA levels with age was also observed in another study, with decreasing levels after the age of 70.[43] Overall, the RBC n-3 and n-6 fatty acids profile in the MaSS population were comparable to a previous study in French community-dwelling older adults.[44]

We observed a lower intake of vitamin B_6 and folic acid and higher homocysteine level in the sarcopenic older adults compared with the nonsarcopenic group. Vitamins B_6, B_{12}, and folate are cofactors of homocysteine metabolism and deficiencies of these vitamins can result in elevated homocysteine levels.[45] It has been hypothesized that these higher homocysteine levels may increase oxidative stress and muscle protein degradation and negatively impact muscle strength and physical functioning in older adults.[26,46]

Although the dietary vitamin D intake was not significantly different between the groups ($P = .053$), we did observe a significantly lower 25-hydroxyvitamin D level in the sarcopenic group. This might indicate that our sarcopenic and nonsarcopenic groups differed in their sun exposure. The sarcopenic older adults in our study received home care more frequently than the nonsarcopenic older adults. This may indicate a higher level of dependence, less time spend outdoors, and, thus, less sun exposure. The multiple regression analysis correcting for possible covariates and subsequent subgroup analysis demonstrated that the difference in 25-hydroxyvitamin D was related to age and living situation. This may indicate that these factors play a role in the observed group difference, rather than primarily the presence of sarcopenia. The discrepancy between the low (<20 μg) vitamin D intake and the mean adequate (>50 nmol/L) 25-hydroxyvitamin D levels illustrates the importance of biomarker assessments when interpreting vitamin D data. Comparable results were found in the B-Vitamins for Prevention of Osteoporotic Fractures Study,[47] in which a total (including supplements) vitamin D intake of 5.2 μg/d was found for those with a

Table 2
Total Daily Nutrient Intake, Including Dietary and Supplement Intake of the Total MaSS Population, and for the Sarcopenic and Nonsarcopenic Participants Separately

	Supplement Users[†]	Dietary Intake				Total Energy and Nutrient Intake[*]		
		Total n = 226	Nonsarcopenic n = 173	Sarcopenic n = 53	*P* Value[‡]	Nonsarcopenic n = 167[§]	Sarcopenic n = 53[§]	*P* Value[‡]
Energy, MJ		7.6 (2.2)	7.7 (2.2)	7.2 (2.2)	.133	7.8 (2.2)	7.2 (2.2)	.119
Energy, kcal		1818 (526)	1847 (525)	1723 (521)	.133	1853 (527)	1724 (521)	.119
Carbohydrate, g		184 (57)	187 (56)	176 (61)	.246	188 (56)	177 (61)	.221
Carbohydrate, En%		41 (6)	41 (6)	41 (7)	.691	41 (6)	41 (7)	.696
Protein, g		73 (21)	74 (20)	68 (22)	.048[‖]	74 (20)	68 (22)	.048[¶]
Protein, g/kg bw		0.98 (0.31)	0.98 (0.29)	0.98 (0.36)	.915	0.97 (0.27)	0.98 (0.36)	.835
Protein, En%		16 (3)	16 (3)	16 (3)	.186	16 (3)	16 (3)	.226
Fat, g		72 (27)	74 (28)	68 (25)	.222	74 (28)	68 (25)	.214
Fat, En%		35 (5)	35 (5)	36 (6)	.909	35 (5)	36 (6)	.861
Alcohol, g		13 (16)	13 (16)	13 (16)	.818	13 (16)	13 (16)	.818
Alcohol, En%		4.9 (5.9)	4.9 (5.7)	5.1 (6.6)	.765	5 (6)	5 (7)	.839
n-3 fatty acids, g	5	2.0 (0.8)	2.0 (0.8)	1.7 (0.7)	.007	2.1 (0.8)	1.7 (0.7)	.005
n-3 fatty acids, En%		1.0 (0.3)	1.0 (0.2)	0.9 (0.3)	.026	1.0 (0.3)	0.9 (0.3)	.022
ALA, 18:3*n*-3, g	1	1.67 (0.69)	1.73 (0.71)	1.47 (0.59)	.019[#]	1.73 (0.72)	1.47 (0.59)	.018[**]
EPA, 20:5*n*-3, g	14	0.08 (0.07)	0.09 (0.08)	0.07 (0.06)	.076	0.10 (0.11)	0.08 (0.07)	.089
DHA, 22:6*n*-3, g	13	0.11 (0.11)	0.12 (0.12)	0.09 (0.09)	.101	0.14 (0.14)	0.10 (0.09)	.064
Vitamin B_6, mg	54	1.6 (0.5)	1.7 (0.5)	1.4 (0.5)	.005	2.9 (8.0)	2.4 (3.8)	.679
Vitamin B_{12}, μg	54	5.0 (2.8)	5.2 (3.0)	4.4 (2.1)	.079	10.7 (45.8)	6.9 (13.9)	.550
Folic acid equivalents, μg	46	305 (112)	319 (110)	260 (104)	<.001	375 (167)	312 (160)	.016[††]
Vitamin C, mg	59	116 (59)	119 (58)	104 (61)	.103	179 (191)	178 (227)	.966
Vitamin D, μg	52	3.6 (1.5)	3.7 (1.6)	3.3 (1.3)	.053	5.2 (3.6)	4.5 (3.0)	.197
Vitamin E, mg	53	13 (5)	13 (5)	11 (4)	.005	18 (19)	19 (30)	.689
Calcium, mg	46	869 (395)	874 (406)	852 (358)	.726	903 (402)	894 (383)	.884
Magnesium, mg	52	308 (93)	317 (92)	279 (92)	.009	350 (125)	305 (132)	.024[‡‡]
Selenium, μg	49	43 (13)	44 (13)	40 (13)	.020[§§]	56 (29)	54 (32)	.632
Zinc, mg	51	10 (3)	10 (3)	9 (3)	.094	12 (5)	11 (6)	.576

‖, ¶, #, **, ††, ‡‡, §§ No longer statistically significant following the multiple regression analysis.
Data are presented as mean (SD).
*Total nutrient intake includes both dietary and supplement nutrient intake.
†Number of subjects consuming micronutrients via a dietary supplement.
‡Comparison sarcopenic vs nonsarcopenic (2 independent samples *t*-test).
§Number of participants for EPA and DHA (nonsarcopenic: n = 166, sarcopenic: n = 53) and alcohol (nonsarcopenic: n = 173. sarcopenic: n = 53).
‖Significant covariates: MNA-SF®, ethnicity, alcohol consumption, MMSE score, comorbidities, weight, height, BMI, physical activity, energy intake.
¶Significant covariates: MNA-SF®, ethnicity, smoking, alcohol consumption, MMSE score, comorbidities, weight, height, BMI, physical activity, energy intake.
#Significant covariates: weight and height, physical activity, energy intake.
**Significant covariates: weight and height, physical activity, energy intake.
††Significant covariates: physical activity, energy intake.
‡‡Significant covariates: age, living situation, height, physical activity, energy intake.
§§Significant covariates: MMSE score, weight, height, physical activity, energy intake.

25-hydroxyvitamin level of >50 nmol/L. In addition the authors of the B-PROOF also observed a decrease in 25-hydroxyvitamin D with age, which is in line with our multiple regression and subgroup analyses. Overall, only 24% of the MaSS population took dietary supplements containing vitamin D, in contrast to the Dutch national recommendation that advices vitamin D supplements for older adults.[48] Both the sarcopenic and nonsarcopenic group had average 25-hydroxyvitamin D levels above 50 nmol/L, however, 51% of the sarcopenic group and 25% of the nonsarcopenic group had a deficient status.[48] Part of the overall MaSS participants are, therefore, at risk of loss of muscle mass, as the Longitudinal Aging Study Amsterdam cohort[27] indicates that older adults with serum levels below 25 nmol and between 25 and 50 nmol/L are at an increased risk of loss of appendicular skeletal muscle mass compared with those with levels equal or above 50 nmol/L.

Table 3
Biochemical Nutrient Status of the Total MaSS Population and for the Sarcopenic and Nonsarcopenic Participants Separately

	Total n = 226[*]	Nonsarcopenic n = 173[*]	Sarcopenic n = 53[*]	*P* Value[†]
25-hydroxyvitamin D, nmol/l	66.8 (31.0)	70.1 (30.3)	56.2 (31.3)	.004[‡]
Magnesium, mmol/l	0.87 (0.08)	0.87 (0.08)	0.87 (0.08)	.941
n-3 fatty acids, %	7.10 (1.15)	7.14 (1.19)	6.98 (1.03)	.390
EPA, 20:5n-3, %	0.91 (0.36)	0.94 (0.38)	0.79 (0.27)	.007[‡]
DPA, 22:5n-3, %	2.13 (0.25)	2.13 (0.25)	2.12 (0.27)	.860
DHA, 22:6n-3, %	3.80 (0.81)	3.80 (0.83)	3.81 (0.74)	.964
n-6 fatty acids, %	28.0 (1.7)	28.0 (1.7)	27.9 (1.6)	.583
LA, 18:2n-6, %	10.4 (1.6)	10.6 (1.6)	9.9 (1.6)	.016
AA, 20:4n-6, %	12.7 (1.3)	12.6 (1.3)	12.9 (1.5)	.196
Homocysteine, μmol/l	12.8 (5.4)	12.1 (4.2)	15.2 (7.9)	<.001
α-tocopherol/cholesterol, μmol/mmol	6.87 (1.15)	6.86 (1.18)	6.92 (1.06)	.730

Data are presented as mean (SD).
*Number of participants for n-3 fatty acids, EPA, DPA, DHA, n-6 fatty acids, LA, AA, homocysteine, α-tocopherol/cholesterol: total n = 225, nonsarcopenic n = 173, sarcopenic n = 52.
†Comparison sarcopenic vs nonsarcopenic (2 independent samples *t*-test).
‡No longer statistically significant following the multiple regression analysis, significant covariates are age and living situation.

The sarcopenic participants differed in their vitamin E intake compared with the nonsarcopenic group, however, no significant difference was observed in the α-tocopherol to total cholesterol ratio. Although a linear relationship has been reported for intake and plasma levels, the strength of this relationship varies among studies,[49] which may explain the observed discrepancy in our results. We also observed a lower selenium intake among the sarcopenic older adults. Vitamin E and selenium might act as antioxidants, addressing oxidative damage. Oxidative damage has been proposed as one of the contributors to sarcopenia, through DNA, lipid and protein damage, and subsequent muscle atrophy.[50,51]

Magnesium intake differed significantly between the sarcopenic group compared with the nonsarcopenic group, however, this was not reflected in a difference in serum magnesium levels. Serum magnesium levels are a useful marker for major deficiencies but may not be sensitive to small differences in magnesium intake.

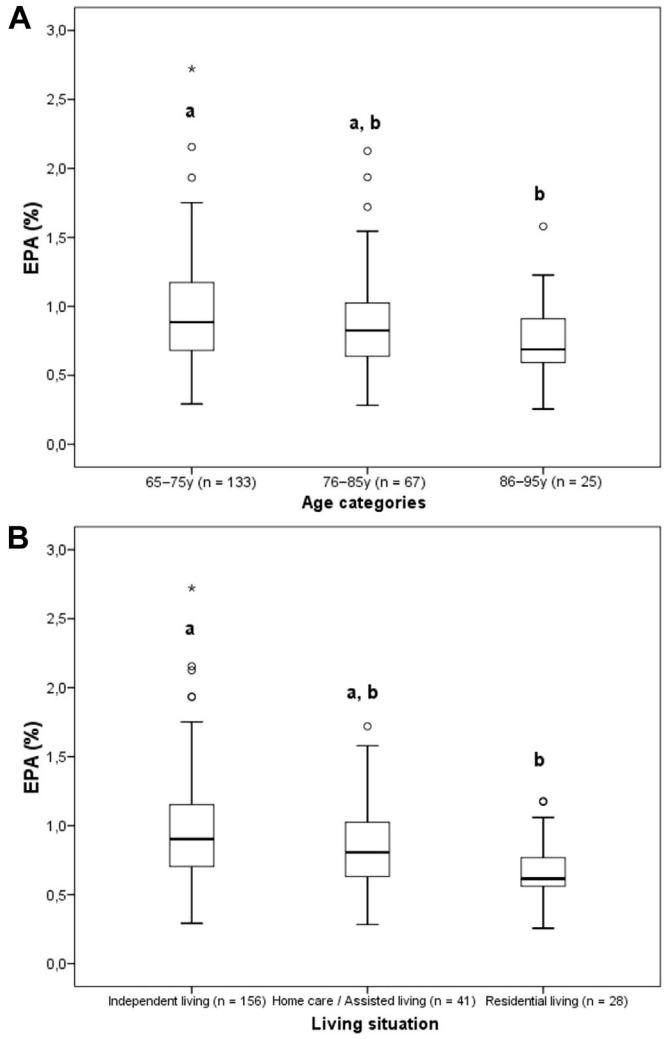

Fig. 2. (A) Box plot representing the RBC EPA level (%) of the total MaSS population, per age category. The boxes represent the interquartile range (IQR), with the median indicated as a bar within the box. The whiskers represent 1.5 times the IQR, outliers are indicated as circles, and extreme outliers with a star. Different letters indicate significant differences in group mean EPA levels ($P < .05$, 1-way analysis of variance (ANOVA) with Tukey all-pairs comparison). (B) Box plot representing the RBC EPA level (%) of the total MaSS population, per living situation. The boxes represent the IQR, with the median indicated as a bar within the box. The whiskers represent 1.5 times the IQR, outliers are indicated as circles and extreme outliers with a star. Different letters indicate significant differences in group mean EPA levels ($P < .01$, 1-way ANOVA with Tukey all-pairs comparison).

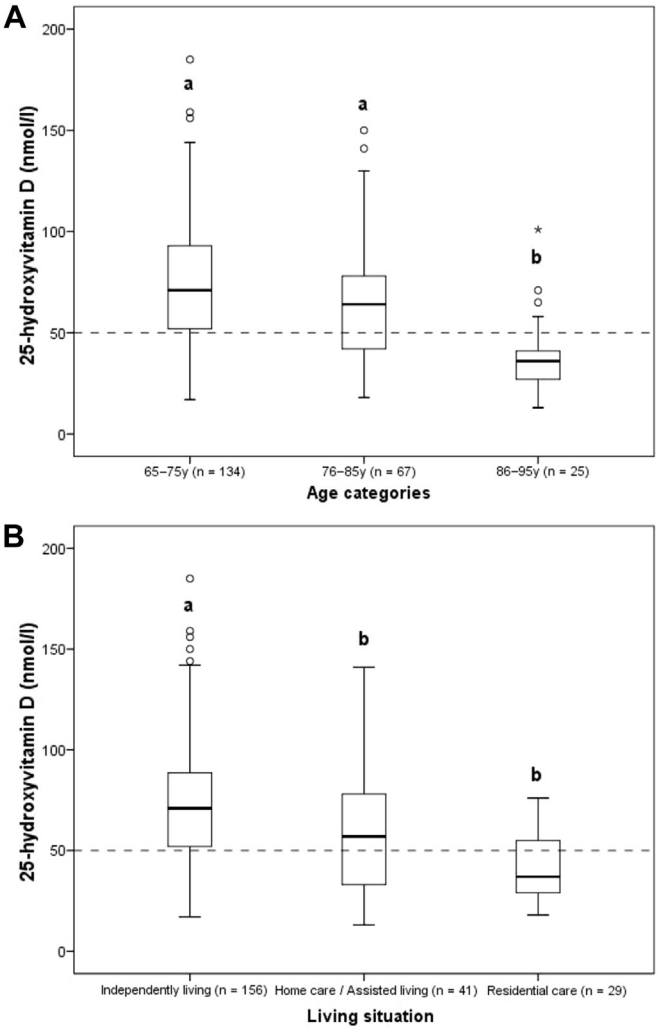

Fig. 3. (A) Box plot representing the 25-hydroxyvitamin D levels of the total MaSS population, per age category. The boxes represent the IQR, with the median indicated as a bar within the box. The whiskers represent 1.5 times the IQR, outliers are indicated as circles, and extreme outliers with a star. Different letters indicate significant differences in group mean 25-hydroxyvitamin D levels ($P < .01$, 1-way ANOVA with Tukey all-pairs comparison). (B) Box plot representing the 25-hydroxyvitamin D levels of the total MaSS population, per living situation. The boxes represent the IQR, with the median indicated as a bar within the box. The whiskers represent 1.5 times the IQR, outliers are indicated as circles and extreme outliers with a star. Different letters indicate significant differences in group mean 25-hydroxyvitamin D levels ($P < .01$, 1-way ANOVA with Tukey all-pairs comparison).

Magnesium levels are kept constant[52] and are strictly regulated by urinary excretion, bone stores, and gastrointestinal tract,[49] which may explain why the difference in magnesium intake was not reflected by a difference in the serum magnesium levels between the 2 groups.

Energy intake did not differ significantly between the sarcopenic and nonsarcopenic groups in the present study, but was identified as a covariate for some of the observed nutrient intake differences. This indicates that there could be a difference in diet quality between sarcopenic and nonsarcopenic older adults in the MaSS population, rather than an overall lower food intake. Among Iranian older adults, adherence to the Mediterranean diet was associated with a lower odds of sarcopenia,[12] which illustrated the importance of diet quality. Understanding the food pattern and food choices of sarcopenic older adults would, therefore, be of added value. Although we did not observe significant differences in energy intake between the 2 groups, it is important to monitor energy intake as anorexia is associated with sarcopenia,[53] and low energy intakes are frequently reported among community-dwelling older adults.[54]

Compared with the nutritional reference values, a low energy intake in the MaSS men was observed. We, however, do not expect that the overall MaSS population was suffering from an energy deficit. Both groups had a maximum MNA-SF® score of 14 with 1% of the total population being malnourished and 9% at risk of malnutrition. The mean BMI of the MaSS population was 27 kg/m^2. The nutritional reference value based on a physical activity level of 1.6, which represents a light active lifestyle, may have overestimated their actual energy need.

The nutrient intake of the MaSS population is comparable to that of the Dutch National Food Survey (DNFCS)[55] and recent systematic literature reviews[54,56] (Appendix Table A1). Only 1 cohort study (KNHANES)[10,11] previously investigated the difference in nutrient intake (ie, energy, protein, carbohydrate, vitamin D, and calcium) between, Korean, sarcopenic, and nonsarcopenic older adults. The

KNHANES found differences in energy, carbohydrate, and calcium intakes between sarcopenic and nonsarcopenic older adults. Although we observed slightly lower carbohydrate intakes in the sarcopenic group, the difference between the 2 groups was not significant. We also did not observe significant differences for calcium intake. Calcium intake in the MaSS population was considerably higher compared with the KNHANES cohort (901 mg vs 410 mg, respectively), indicating that the MaSS older adults had adequate access to calcium-rich foods. Differences in sarcopenia definition (appendicular skeletal muscle mass to body weight ratio of at least 2 standard deviations below the mean for young adults), methodology, and participant characteristics may explain the different findings in the Korean and the MaSS cohorts.

Several strengths and limitations need to be mentioned. One of the strengths of the present study is the comprehensive assessment of dietary and supplement intake and biomarker nutrient status, as well as sarcopenia determinants. It, therefore, provides a more complete overview than most other publications that focus on 1 single nutrient and a specific muscle parameter. The MaSS population was recruited in Maastricht and is a representative sample (based on age, sex, cognition, BMI, smoking) of healthy Dutch community-dwelling older adults compared with the DNFCS.[55] The analysis of dietary supplement intake is of added value, as for certain nutrients the supplements contributed to up to one-third of their total nutrient intake and may have affected their nutritional status and subsequently their health (eg, sarcopenia). In addition, the inclusion of biochemical nutrient markers and covariates with the multiple regression analysis has strengthened the conclusion of the present study.

There are also several limitations that should be considered when interpreting the results of the present study. An FFQ was used to assess the habitual nutrient intake. Although it is a valid method to assess habitual intake, an older adult population may have difficulties with recalling all foods and community-dwelling older adults are known to underreport their energy intakes by 10%-15%.[55,57] Our results on dietary intake are, however, in line with the DNFCS,[55] which used two 24-hour dietary recalls to assess intake. The observed differences in intake may be related to differences in underreporting between sarcopenic and nonsarcopenic older adults. We, however, do not have grounds to believe that those suffering from sarcopenia differ in their reporting from nonsarcopenic older adults. As we use the FFQ, we might have underestimated the variance in dietary intake of our MaSS population. In addition, we were not able to assess the prevalence of underreporters. Including supplement intake increased the nutrient intake variation, which may have influenced our ability to detect significant differences between the groups. The statistical method used to correct for possible confounding factors assumed a linear relationship between the dependent variable and the possible confounding factor. The validity of these models may depend on whether this assumption was justified. As the present study had a cross-sectional design, no conclusions can be made on a causal relationship between the observed nutrient differences and sarcopenia. Longitudinal studies may provide further insight whether the observed differences in nutrient intake can lead to changes in (the determinants of) sarcopenia.

Conclusions

Sarcopenic older adults had a 10%–18% lower intake of 5 nutrients (n-3 fatty acids, vitamin B_6, folic acid, vitamin E, and magnesium) compared with nonsarcopenic older adults. For the 2 biochemical status markers, LA and homocysteine, a 7% and 27% difference was observed, respectively. Dietary supplement intake seems to reduce the gap for some of these nutrients. Targeted nutritional intervention may, therefore, improve the nutrient intake and biochemical nutrient status of sarcopenic older adults.

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Supplementary Data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jamda.2015.12.015.

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